Results from DOE’s Gasoline/Diesel PM Split Study and EPA’s High Mileage OBD Study

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Presentation to the

California I/M Review Committee

November 22, 2005

Results from DOE's Gasoline/Diesel PM Split Study – Overview and LD Vehicle Emissions Data

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Acknowledgment

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Gasoline/Diesel PM Split Study

<u>Objective:</u> To quantify the relative importance of PM emissions from gasoline (SI) and diesel (CI) engines in the South Coast Air Basin

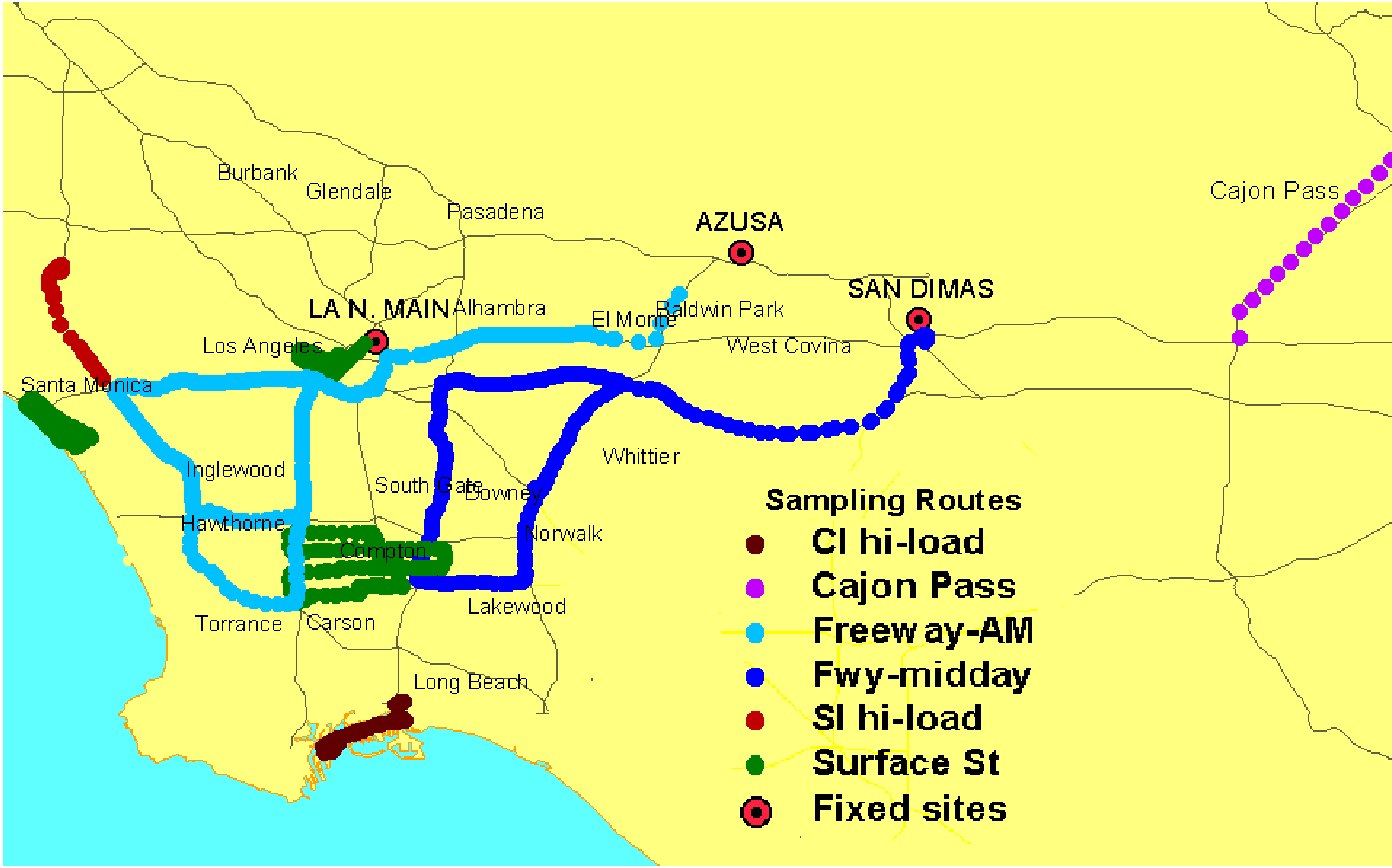
<u>Participants:</u> BAR and SCAQMD (LD vehicle recruitment); Ralphs Grocery Distribution Center; EPA and CAVTC (LD vehicle dynamometer measurements); WVU (HD vehicle dynamometer measurements); DRI and U WI-Madison (source & ambient measurements, source apportionment)

Gasoline/Diesel PM Split Study

Approach:

- Perform source testing of large set of gasoline- and diesel-powered motor vehicles using EPA's and WVU's transportable dynamometers (May-September 2001)
- Collect concurrent ambient samples at a variety of locations (source areas and regionally representative sites – June 20-July 27, 2001). Ambient sampling conducted at two SCAQMD monitoring sites plus several source sites, along with mobile sampling on freeways
- Analyze all collected data from source and ambient samples [PM and semi-volatile organic compounds (SVOCs)] chemically – completed March 2003 (analyses by DRI and UWM)
- Construct source profiles and perform Chemical Mass Balance Receptor modeling (independent and blind analyses by DRI and UWM)
- Submit papers for peer-reviewed publication

Fixed Site and Mobile Ambient Sampling



- Downtown Los Angeles and Azusa - daily 24-hour samples for four consecutive weeks, composited by day of week
- Variety of locations with variable amount of gasoline and diesel traffic

Features of Study and Caveats

- Study performed in Los Angeles during summertime
  - No cold, cold-start emissions measured (especially important for SI vehicles)
  - Maximum amount of secondary carbonaceous PM formed (greatest challenge for CMB modeling because of large amount of unresolved “organic” carbon)
- Vehicles sampled “as is” with California fuels
- Results represent on-road fleet characteristics and ambient data during the summer of 2001; future on-road HD regulations (2007 and 2010) will reduce fleet emissions.
- Mobile emissions profiles from this study should not be used in other parts of California, under cool or cold ambient temperature conditions, or the rest of the country until it can be demonstrated that source profiles under those conditions are chemically similar to those obtained in this program

LD Vehicle Recruitment Sample

Vehicles tested in June 2001

Category	Model Year	Odometer (miles)	Number of Vehicles	Number of Composites
1	1996 and newer	low mileage (< 50,000)	4	1
2	1993-95	low mileage (< 75,000)	4	1
3	1996 and newer	high mileage (> 100,000)	4	1
4	1990-92	lower mileage (< 100,000)	4	1
5	1993-95	higher mileage (> 125,000)	8	2
6	1990-92	> 125,000	9	3
7	1986-89	> 125,000	6	3
8	1981-85	> 125,000	6	3
9	1980 and earlier	> 125,000	6	3
10	Smoker	no model year or odometer criteria	6	6
11	LD Diesel	no model year or odometer criteria	2	2
		Total	59	26

Gasoline/Diesel PM Split Study –
Light-Duty Vehicles Conditioned Using BAR Smog Check ASM Tests

Gasoline/Diesel PM Split Study –

Light-Duty Vehicles Tested Over Unified Driving Cycle

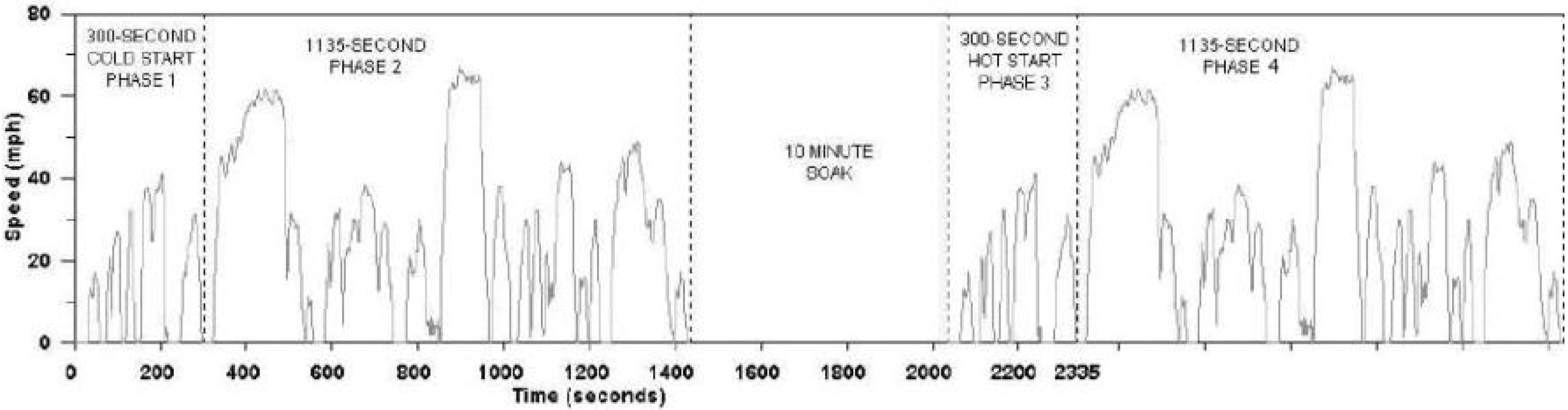
Gasoline/Diesel PM Split Study –
LDV and HDV Exhaust Sampling Systems

Gasoline/Diesel PM Split Study –

Light-Duty Vehicle Driving Cycle:

Modified Unified Driving Cycle (LA-92)

Cold Phase Warm Phase



- Modified Unified Cycle – Phases 3 and 4 are a warm repeat of phases 1 and 2
- 2 sampling phases: “Cold” phase and “Warm” phase, each lasting 1435 seconds; 24.6 mph ave. speed; 67 mph max. speed; 6.9 mph/sec max acceleration
- PM Summary Statistics: Min=0 mg/mi; Max=185 mg/mi; Mean=19 mg/mi; Median=5 mg/mi; Mode=0 mg/mi (skewed distribution)

Gasoline/Diesel PM Split Study – LD Vehicle Recruitment

Recruitment:

- BAR recruited first 9 LD vehicle categories; BKI recruited “smokers” and diesels
- Incentives: $200 and free rental car; $50 if vehicle was rejected; free repairs up to $500 if vehicle failed California Smog Check inspection

Rejects and Why:

- 74 vehicles recruited; 15 rejected
  - 6 rejected because category was over-recruited
  - 4 due to engine/exhaust problems; 3 were too large/incompatible with EPA’s transportable dynamometer
  - 2 for other reasons: engine rebuilt at 230,000 miles; owner brought in vehicle wrong day

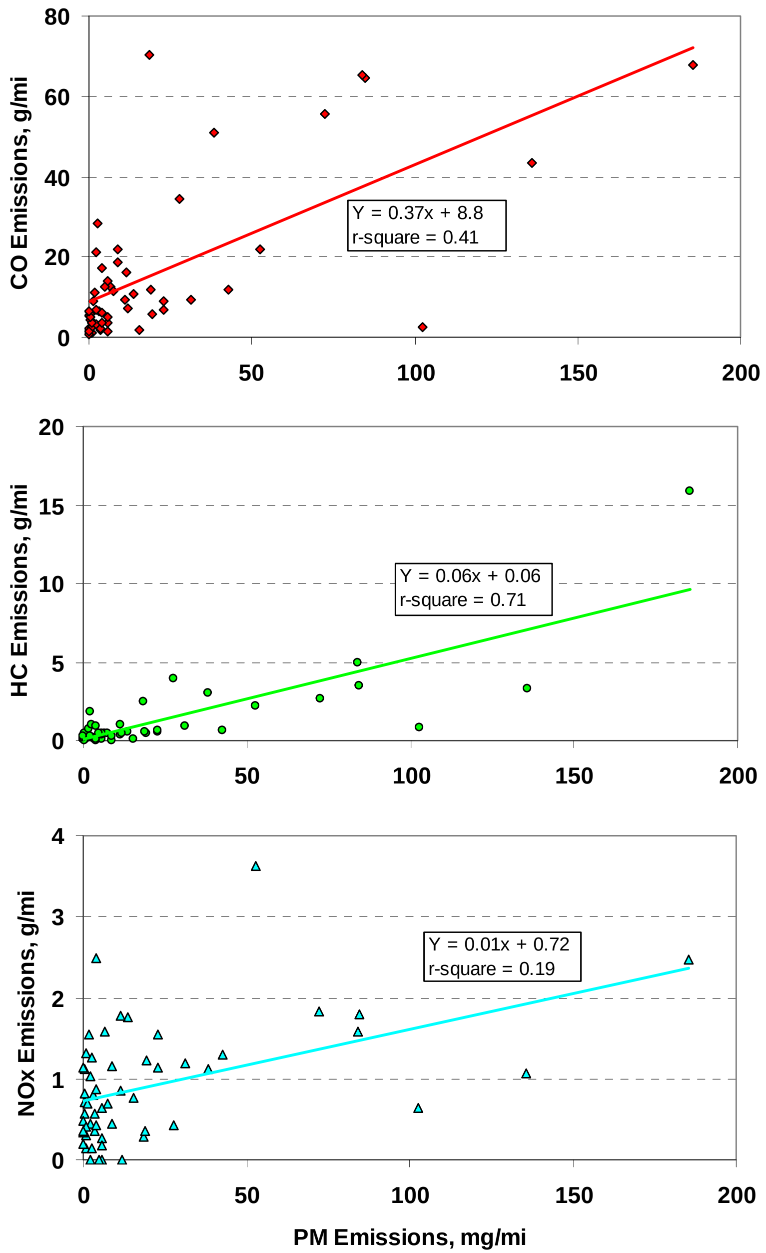
Other Vehicle Problems:

  - 1 overheated on cold phase of Unified Cycle
  - 1 had brakes catch fire during cold phase of Unified Cycle

Smog Check Results:

- 33 vehicles passed Smog Check (I/M) inspection; 24 vehicles failed
  - 7 “gross polluters” according to Smog Check criteria; 5 were tampered with
  - the only 1996+ vehicle that failed Smog Check did not have its MIL illuminated (OBD “false pass”)
  - 2 aborted Smog Check inspections; 2 vehicles were diesels

Gasoline/Diesel PM Split Study



Gasoline/Diesel PM Split Study
HD Vehicle Recruitment & Test Matrix

GVW (lbs.)	Pre 90	90-93	94-97	98-current	Total
	BOX 1	**BOX 2**	**BOX 3**	**BOX 4**	
	Total 1	Total 1	Total 2	Total 4	8
	(C) [1]	(C) [2]	(B) [3]	(D) [5]	
			(C) [4]	(C) [6]	
				(C) [7]	
8501> 14000				(C) [34]	
	BOX 5	**BOX 6**	**BOX 7**	**BOX 8**	
	Total 2	Total 0	Total 3	Total 3	8
	(C) [8]		(B) [10]	(D) [13]	
	(C) [9]		(C) [11]	(B) [14]	
14001> 33000			(C) [12]	(C) [15]	
	BOX 9	**BOX 10**	**BOX 11**	**BOX 12**	
	Total 2	Total 3	Total 6	Total 5	16
	(B) [16]	(B) [18]	(C) [21]	(E) [26]	
	(E) [17]	(C) [19]	(C) [22]	(B) [27]	
		(C) [20]	(C) [23]	(C) [28]	
			(C) [24]	(C) [29]	
			(C) [25]	(C) [30]	
33001> 80000			(C) [33]		
Total	5	4	11	12	32

Transit Buses	
One Powered By Electronic Controlled Diesel - (A)	[32]
One Powered By Manual Controlled Diesel - (A)	[31]

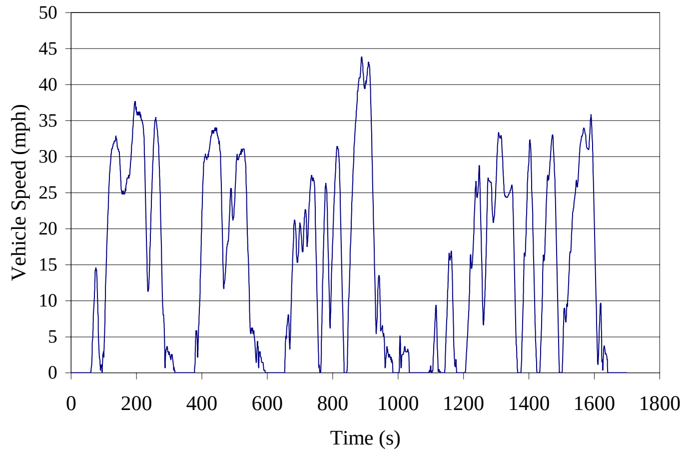
Letters in ( ) are Set ID
Numbers in [ ] are Vehicle Number

Cycle Set:
(A) CSHVR + Manhattan + Idle
(B) Cold CSHVR + CSHVR + Highway +Idle
(C) CSHVR + Highway +Idle
(D) Cold CSHVR + Highway + Idle + Repeat CSHVRs
(E) Cold CSHVR w/engine brake + CSHVR + Highway + Idle + Cold Idle + UDDS + CSHVR w/engine brake

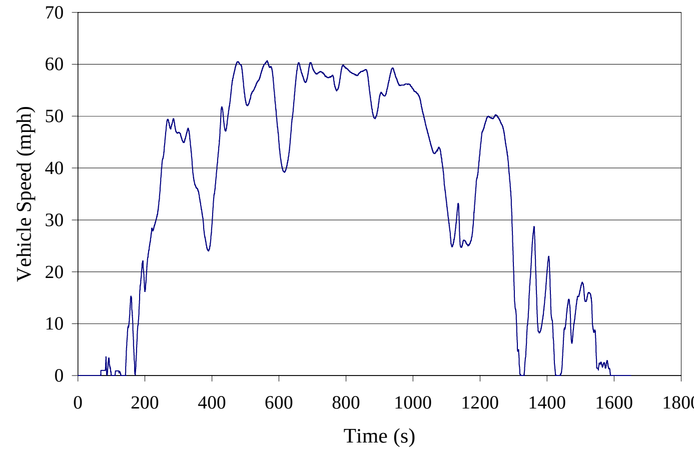
All vehicles tested with CA diesel fuel; 5 tested with federal diesel fuel

Gasoline/Diesel PM Split Study –
Heavy-Duty Vehicles Tested Over Several Driving Cycles

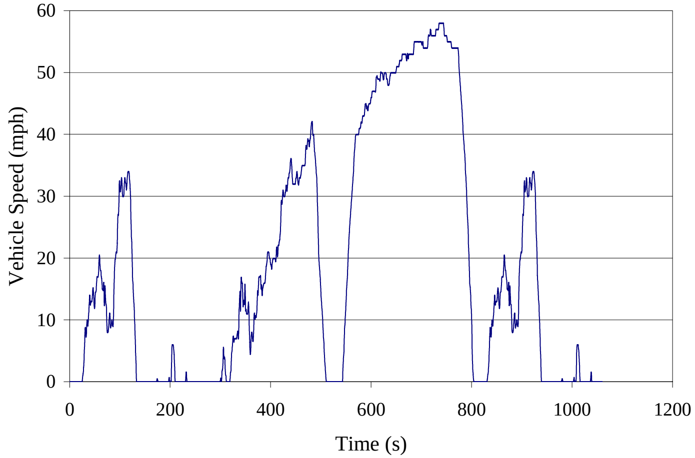
Gasoline/Diesel PM Split Study –
Heavy-Duty Vehicle Test Cycles



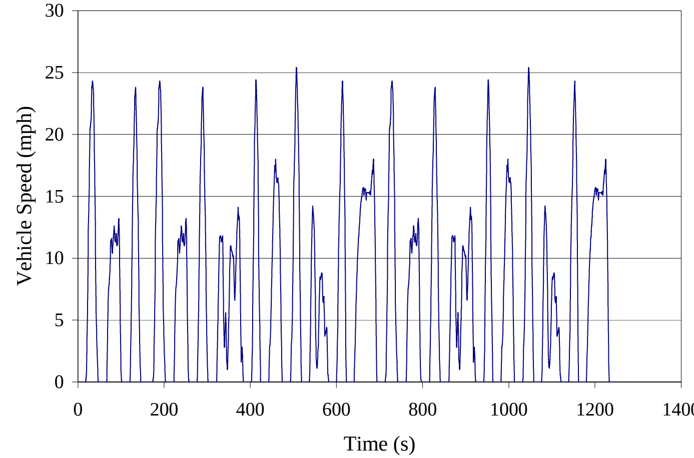
City/Suburban Heavy Vehicle Route (CSHVR)



Highway

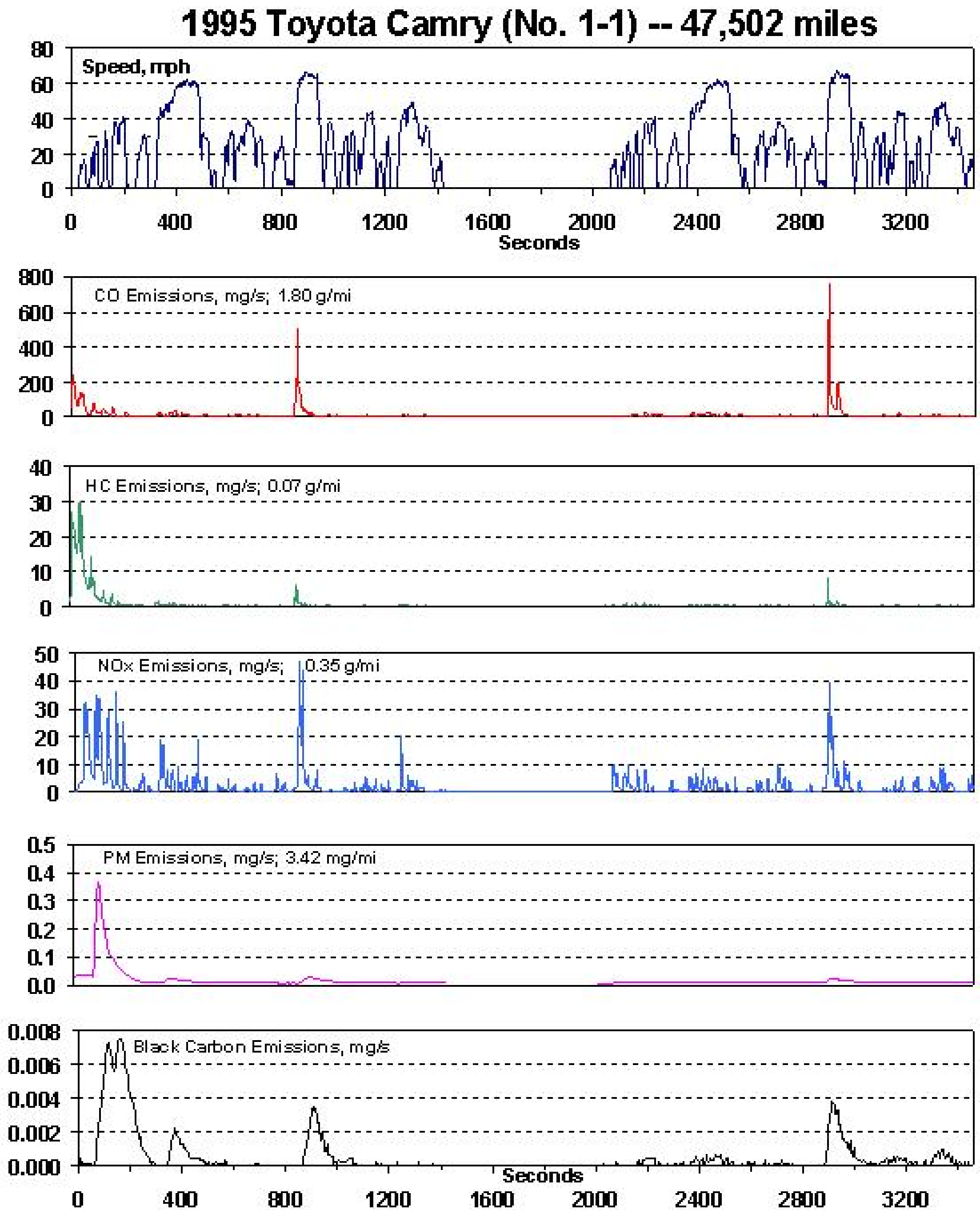


HD Urban Dynamometer Driving Schedule (UDDS)

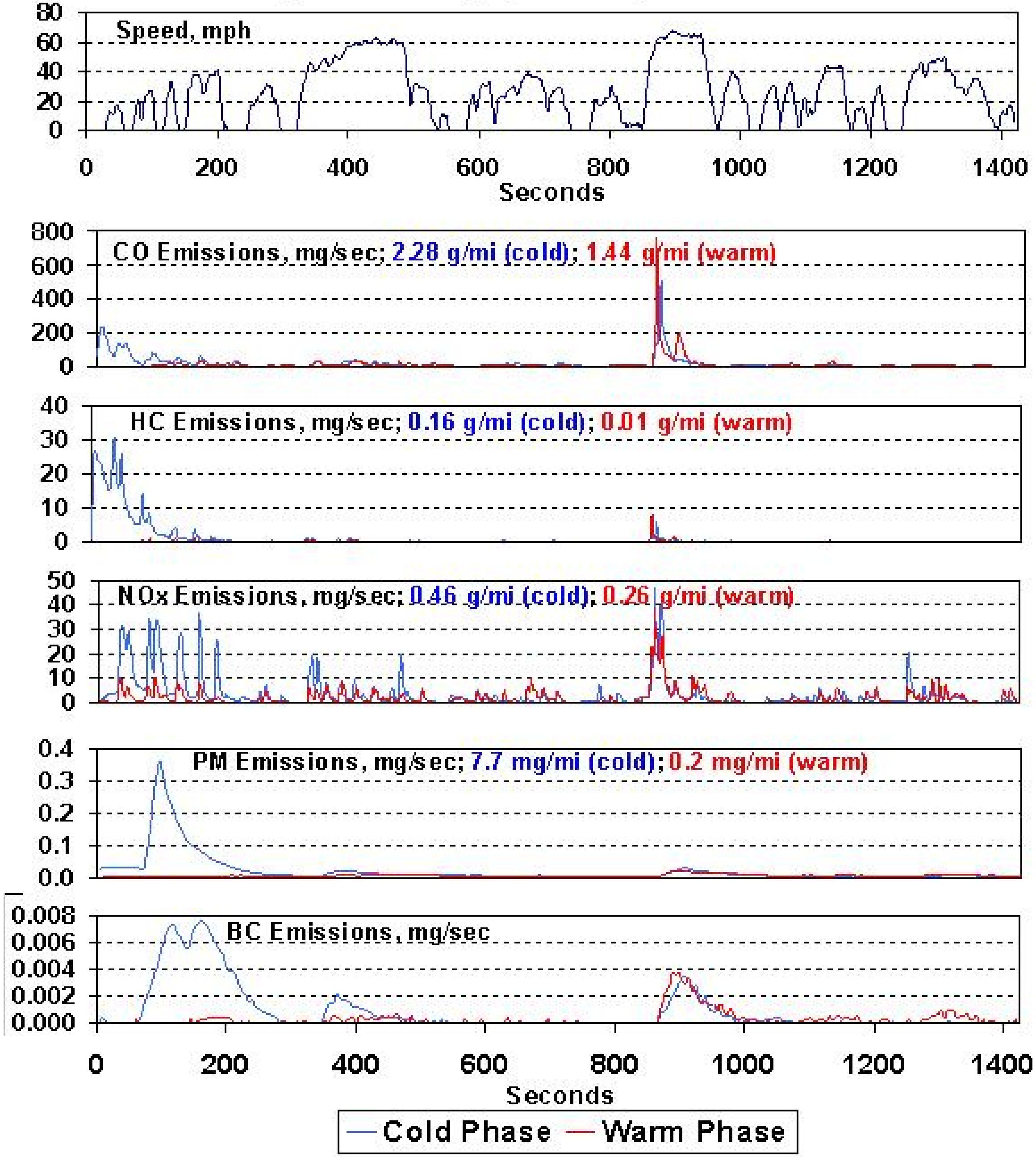


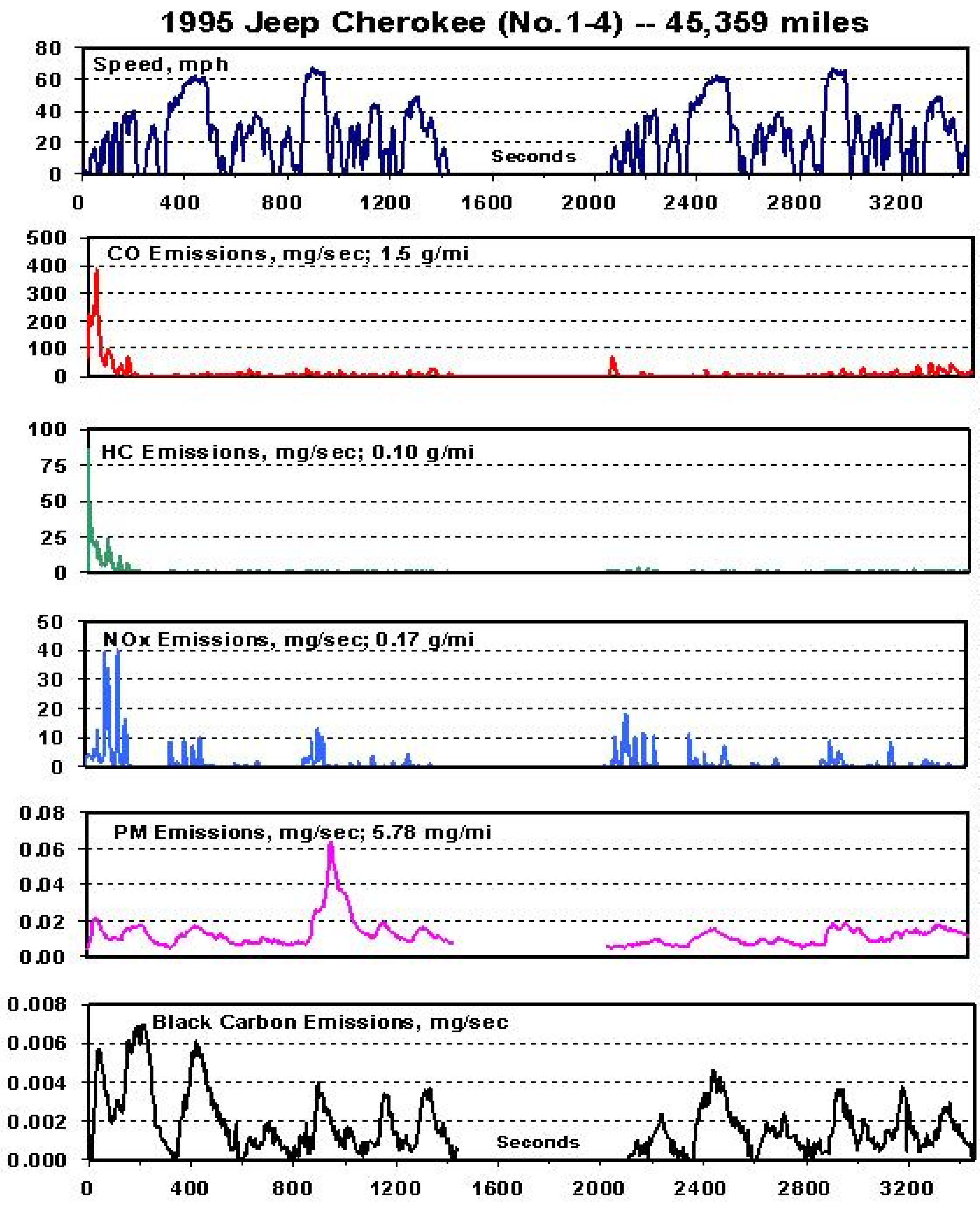
Manhattan

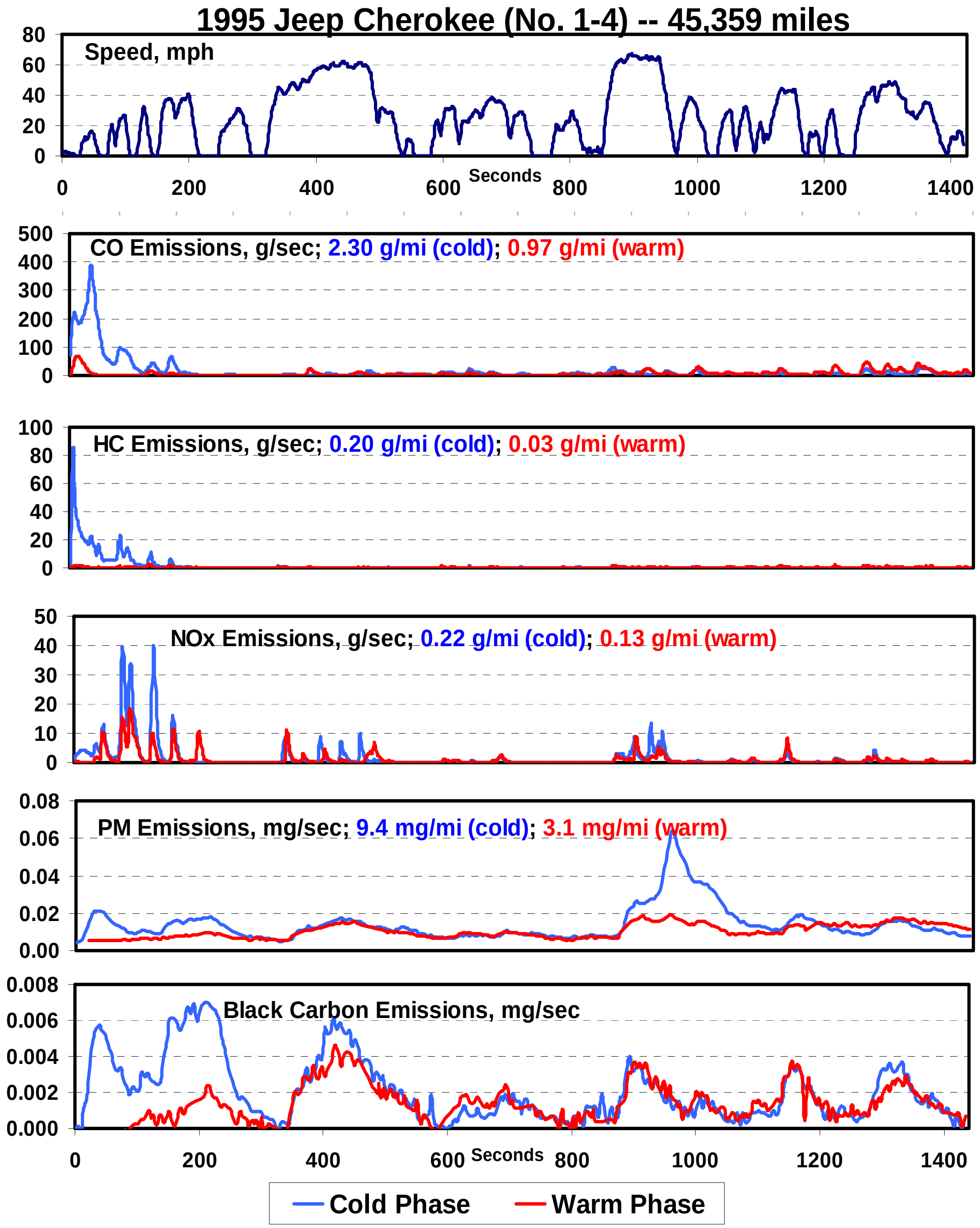
Second-by-Second Data from Light-Duty SI Vehicles


1995 Toyota Camry (No. 1-1) -- 47,502 miles
Speed, mph
CO Emissions, mg/s; 1.80 g/mi
HC Emissions, mg/s; 0.07 g/mi
NOx Emissions, mg/s; 0.35 g/mi
PM Emissions, mg/s; 3.42 mg/mi
Black Carbon Emissions, mg/s
Seconds

1995 Toyota Camry (No. 1-1) -- 47,502 miles




1995 Jeep Cherokee (No.1-4) -- 45,359 miles
Speed, mph
CO Emissions, mg/sec; 1.5 g/mi
HC Emissions, mg/sec; 0.10 g/mi
NOx Emissions, mg/sec; 0.17 g/mi
PM Emissions, mg/sec; 5.78 mg/mi
Black Carbon Emissions, mg/sec
Seconds


1995 Jeep Cherokee (No. 1-4) -- 45,359 miles
Speed, mph
CO Emissions, g/sec; 2.30 g/mi (cold); 0.97 g/mi (warm)
HC Emissions, g/sec; 0.20 g/mi (cold); 0.03 g/mi (warm)
NOx Emissions, g/sec; 0.22 g/mi (cold); 0.13 g/mi (warm)
PM Emissions, mg/sec; 9.4 mg/mi (cold); 3.1 mg/mi (warm)
Black Carbon Emissions, mg/sec
Seconds
Cold Phase
Warm Phase

Mobile Source Air Toxics Data

(Light-duty SI Vehicles)

EPA's List of Mobile Source Air Toxics (MSATs)

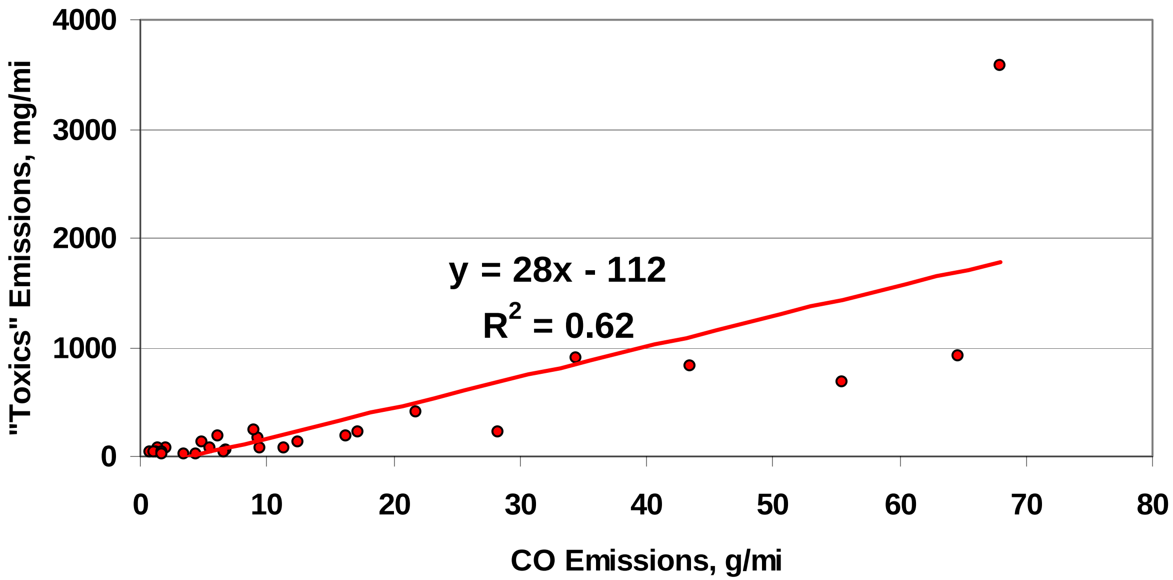
Acetaldehyde	Diesel exhaust	MTBE
Acrolein	Ethylbenzene	Naphthalene
Arsenic compounds	Formaldehyde	Nickel compounds
Benzene	n-Hexane	POM (Sum of 7 PAHs)
1,3-Butadiene	Lead compounds	Styrene
Chromium compounds	Manganese compounds	Toluene
Dioxins/furans	Mercury compounds	Xylenes

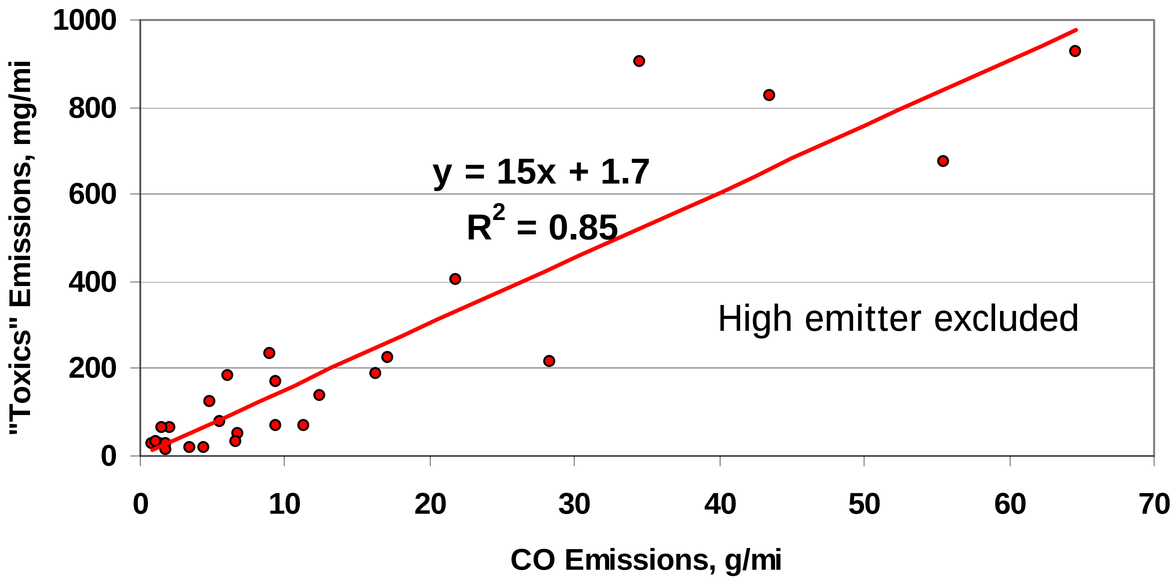
Red = Measured in this study

Orange = not reported due to stability problems in canisters

Gasoline/Diesel PM Split Study

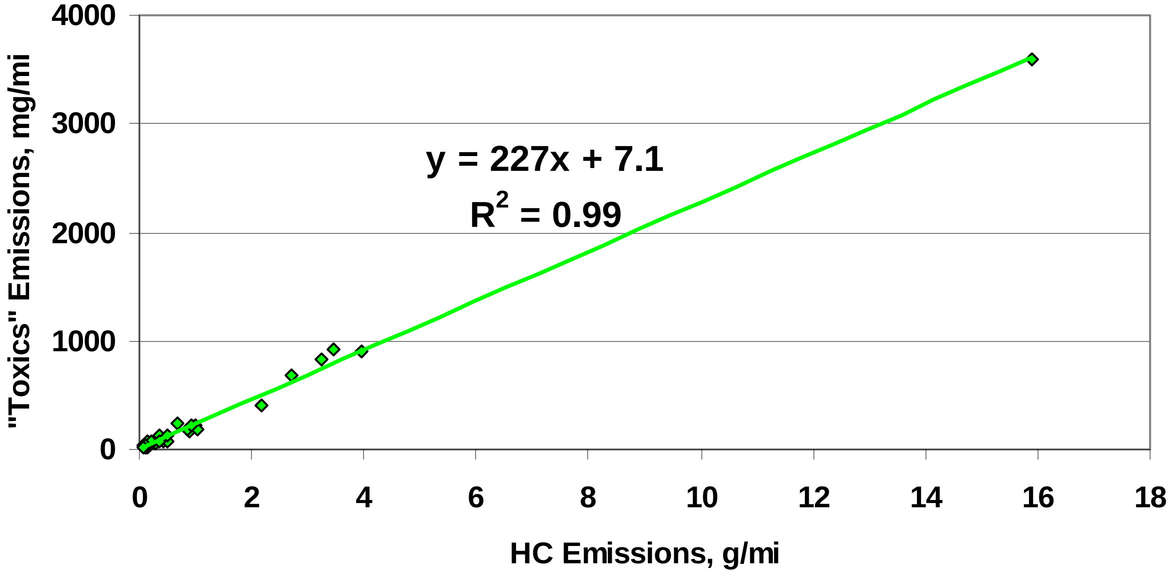
(Sum of 12 species, less 1,3-butadiene)

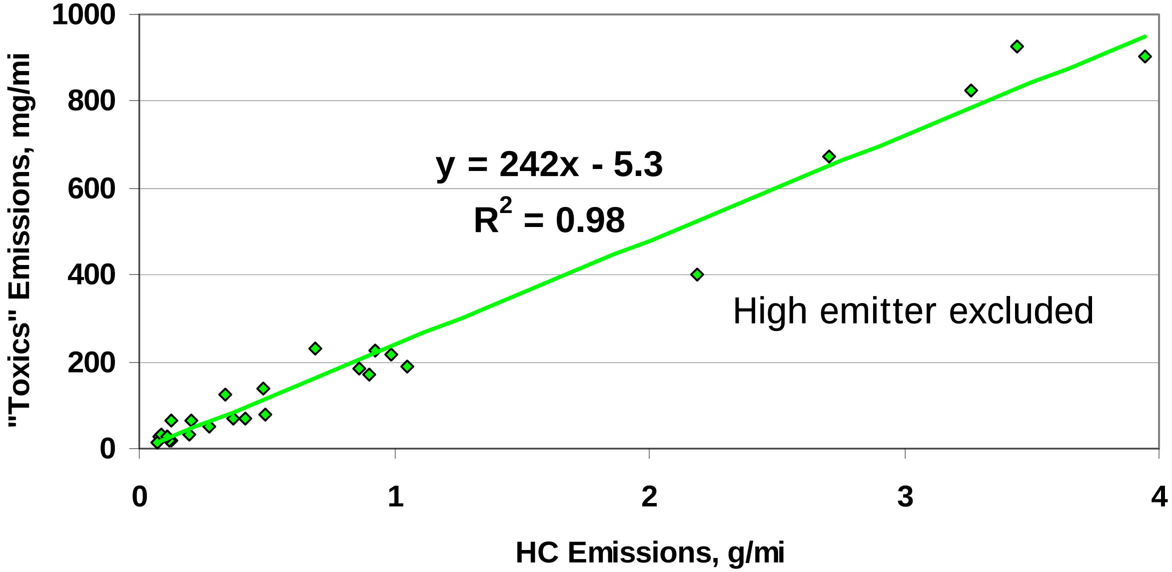




Gasoline/Diesel PM Split Study

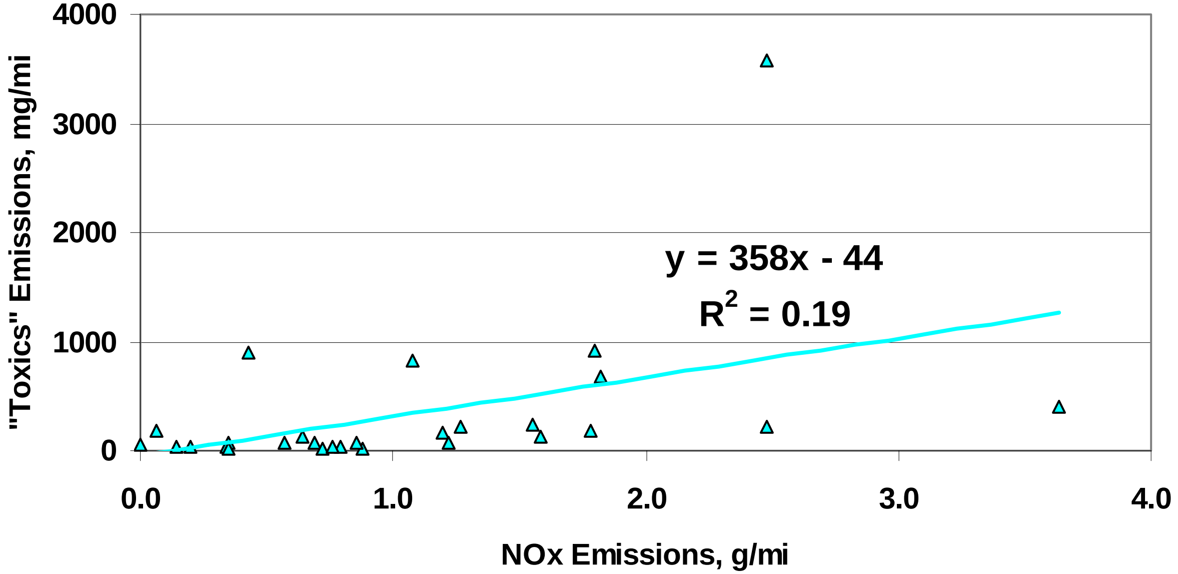
(Sum of 12 species, less 1,3-butadiene)

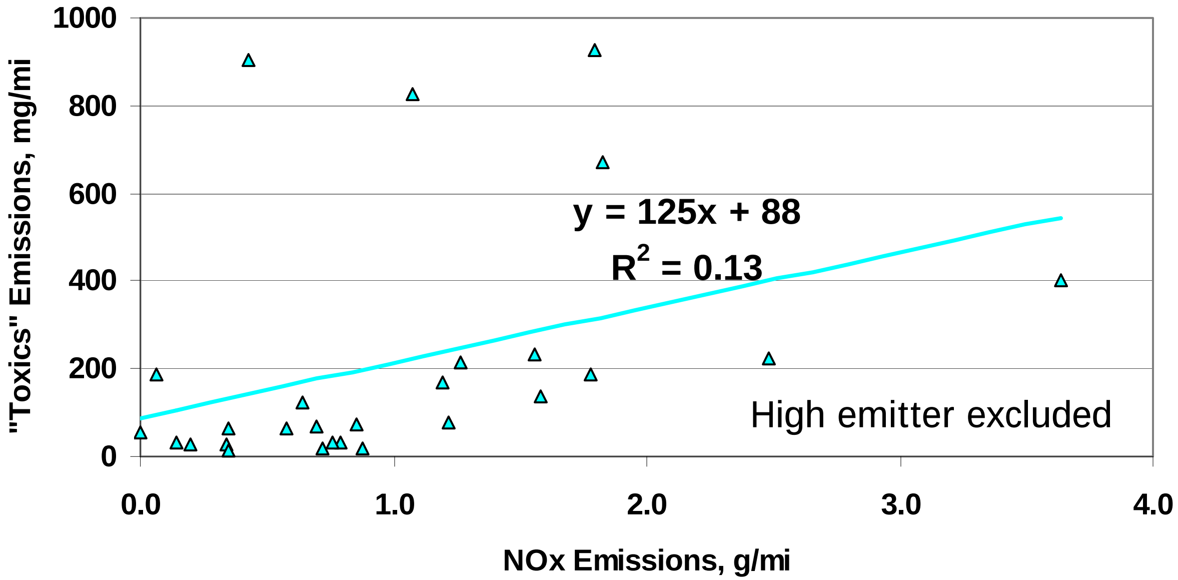




Gasoline/Diesel PM Split Study

(Sum of 12 species, less 1,3-butadiene)

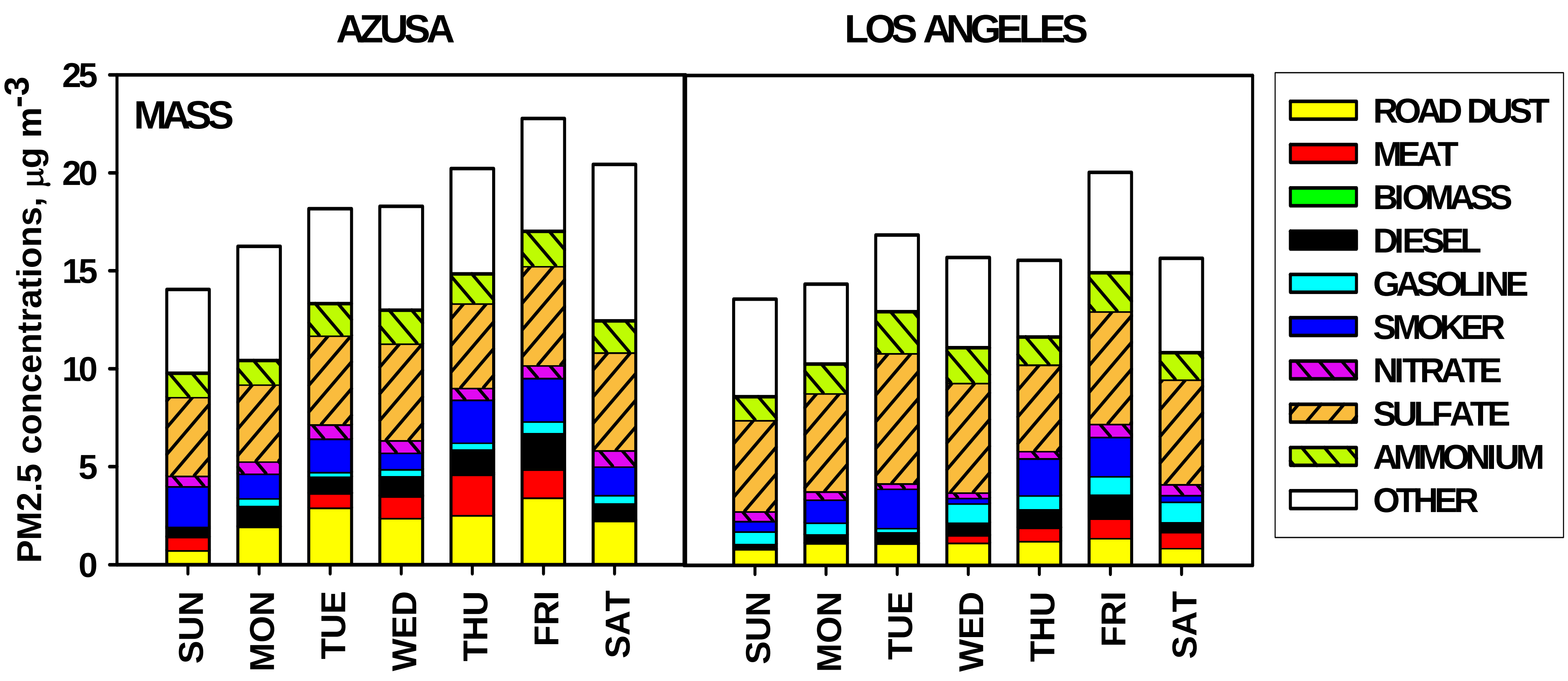




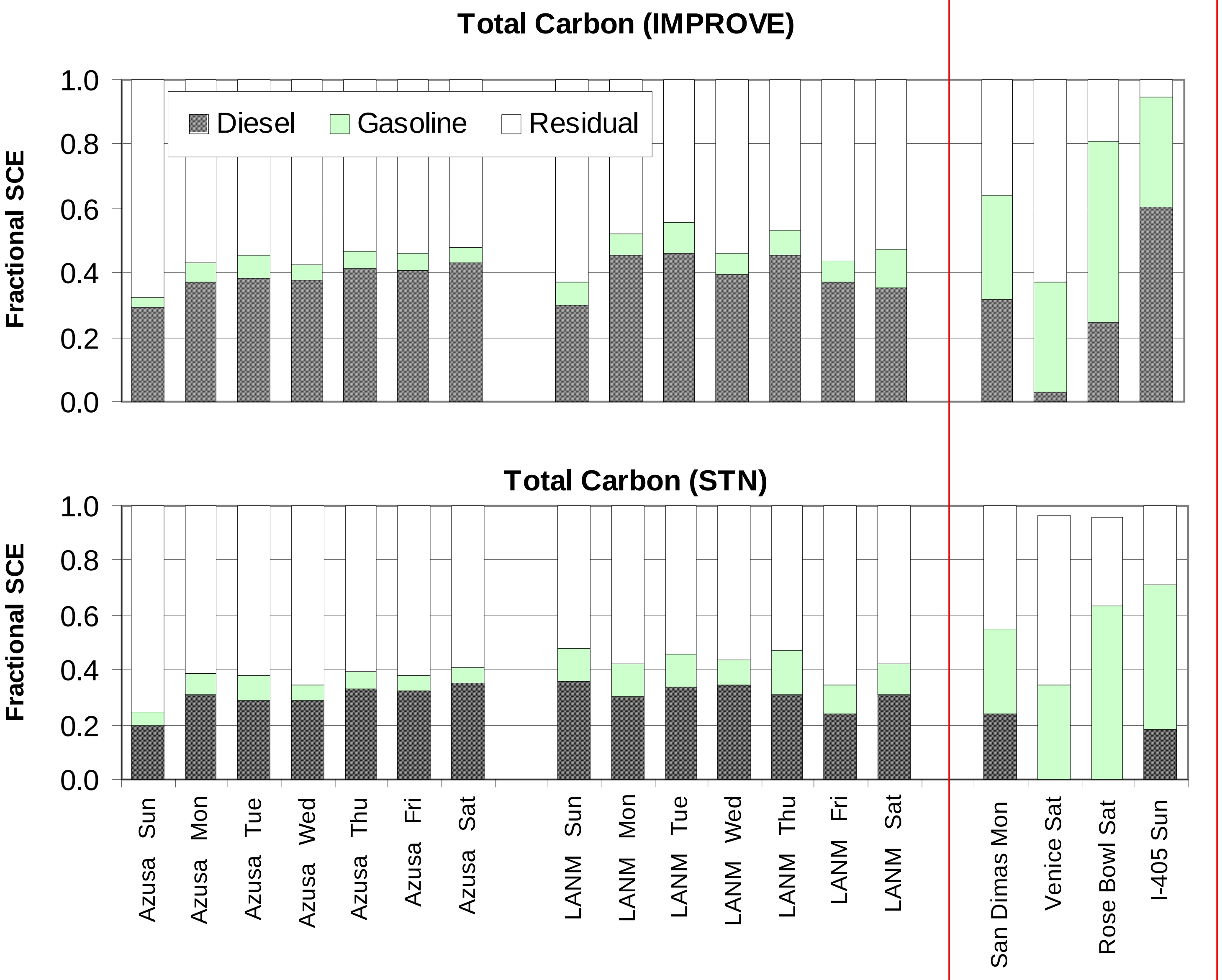
Observations/Implications

- The sampled spark-ignition fleet was weighted toward older, high mileage vehicles, where the ten highest PM, HC, CO, and NO_x emitters contributed 66, 66, 58, and 39%, respectively, of the total PM, HC, CO, and NO_x emissions from the 57 SI vehicles tested. A VMT-weighted fleet will have even more emissions skewness.
- The ten highest PM emitters were also the seven, eight, and five highest HC, CO, and NO_x emitters, respectively.
- For "normal" emitter SI vehicles, nearly all of the PM is from cold start and hard acceleration conditions. The number of high emitters and the amount and composition of emissions they produce is critical.
- "Normal" emitter SI vehicles produce "elemental" carbon emissions.
- Excellent correlation between total hydrocarbons as measured by heated FID and sum of mobile source air toxics HC species collected in canisters and analyzed by GC/MS.
- Cold phase PM emissions significantly higher than warm phase PM emissions for SI vehicles; only slightly higher for the 2 LD diesel vehicles. This has important implications for ambient cold start conditions cooler than room temperature for SI vehicles.
- Source profiles developed during this study should not be used for other seasons/locations until mobile emissions profiles from those seasons/areas can be shown to be similar to those from this program.

Group 1: Source Contributions to $PM_{2.5}$ at Azusa and Los Angeles by Day of Week, July 2001



Group 2: Source Contributions to Total Carbon at Various Sites



Study Findings

- Two different groups, working independently, produced somewhat different source apportionments for gasoline and diesel contributions to ambient PM in the South Coast Air Basin
- Gasoline PM emissions are more important than diesel PM to ambient PM concentrations at certain times and locations.
- High-emitting gasoline vehicles are very important contributors to ambient PM
- There is some correlation between high gas-phase and high particle-phase emitters in gasoline vehicles.

Data and reports from
the DOE’s Gasoline/Diesel PM Split Study
are available at
http://www.nrel.gov/vehiclesandfuels/nfti

On-Board Diagnostics (OBD)

From National Academy of Sciences' NRC Committee on "Evaluating Vehicle Emissions Inspection and Maintenance Programs" (2001):

On-Board Diagnostics (pp.11-12)

<u>Findings and Recommendations</u>

"The committee found that the current data set for evaluating the effectiveness of OBDII for I/M testing is inadequate."

"An independent evaluation should be established, with appropriate funding, using researchers outside the agencies to review the effectiveness and cost-effectiveness of OBDII testing programs before moving forward with full implementation of OBDII rule requirements."

EPA's High Mileage OBD Study

Gardetto *et al*., *J. Air & Waste Manage. Assoc.*, Oct. 2005

Objectives

- Evaluate effectiveness of OBD systems to identify emissions problems in high mileage vehicles
- Compare effectiveness of repairs according to OBD and IM240 failures

Data for this analysis kindly provided by Ed Gardetto

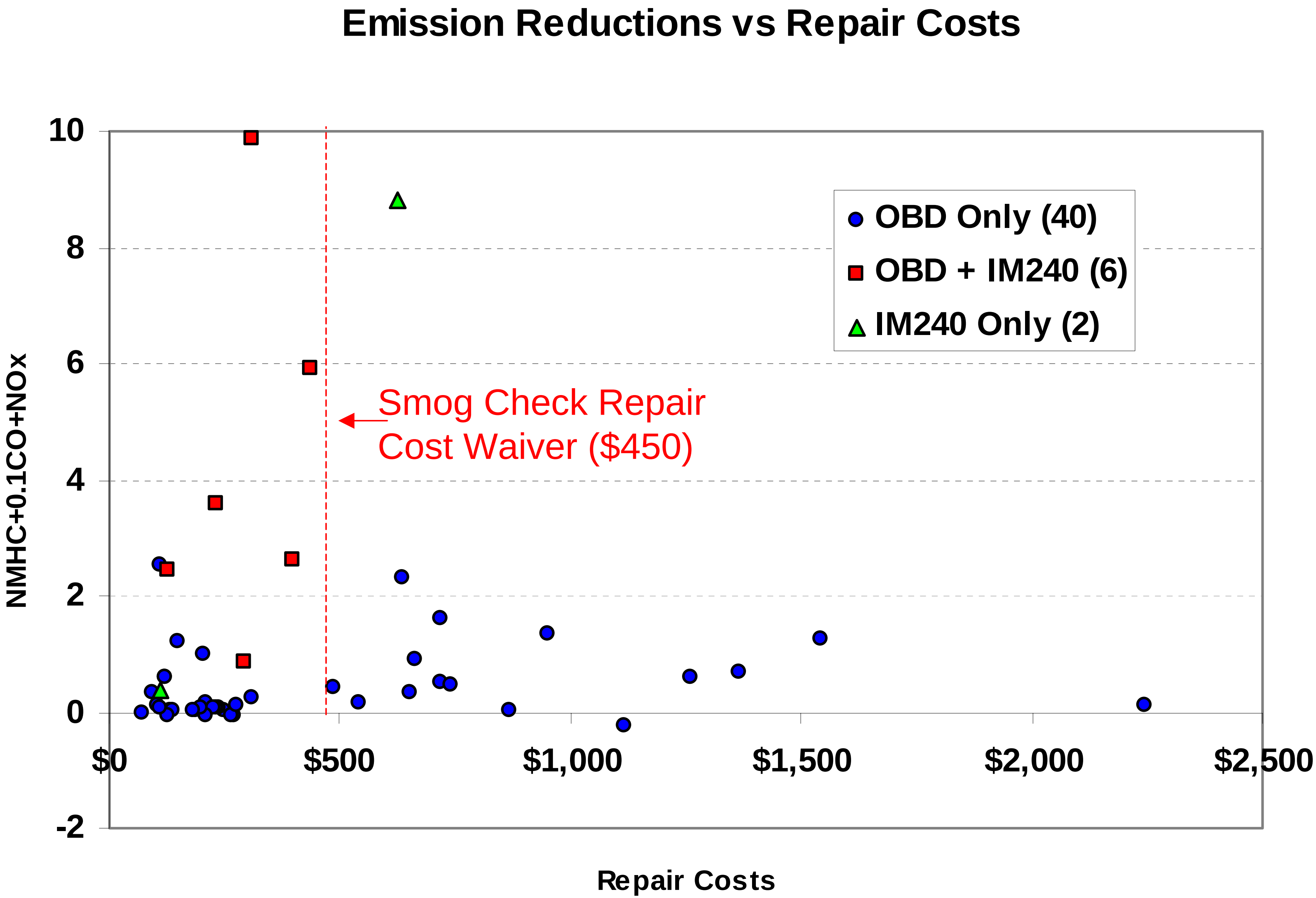
Approach

- Recruit high mileage (>100,000 miles) light-duty cars and trucks (only criterion)
- Vehicles recruited in AZ (61); CO (8); MI (84); total of 153
- Repairs:
  - Any vehicle with MIL illuminated was repaired according to MIL illumination
  - Any vehicle not failing MIL but failing IM240 repaired according to EPA's final IM240 cutpoints
  - Other vehicles repaired but not focus of this presentation
- Test Sequence for Vehicles in this presentation:

  Lab IM240 → LA-4 → FTP → IM240 → Repairs → LA-4 → FTP → IM240
- Best possible scenario for repairs; does not represent real-world I/M repair process because vehicles were taken from the owner, and technicians knew their performance was being monitored

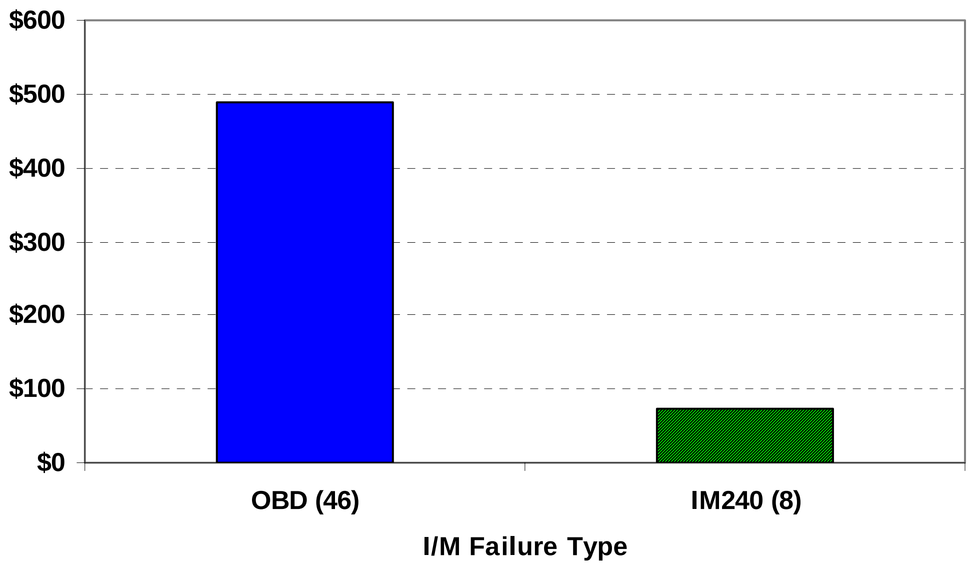
Vehicles in Repair Study

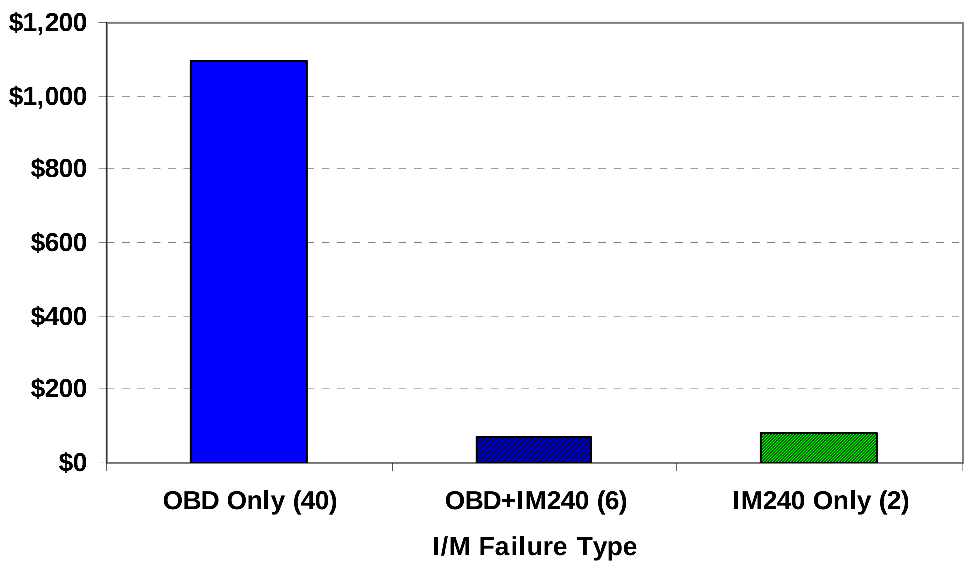
- In the 153 vehicle data set
  - 46 failed with MIL illuminated (30.3%)
  - 9 failed IM240 test (6.3%; 1 could not be repaired and dropped from study)
- Of the 48 vehicles with pre- and post-repair FTP data:
  - 46 failed with the MIL illuminated; 6 of these failed the IM240 (all repaired according to OBD criteria)
  - 2 failed the IM240 but their MIL was not illuminated (these repaired according to IM240 criteria)


Emission Reductions vs Repair Costs
10
8
6
4
2
0
-2
NMHC+0.1CO+NOx
$0
$500
$1,000
$1,500
$2,000
$2,500
Repair Costs
OBD Only (40)
OBD + IM240 (6)
IM240 Only (2)
Smog Check Repair
Cost Waiver ($450)

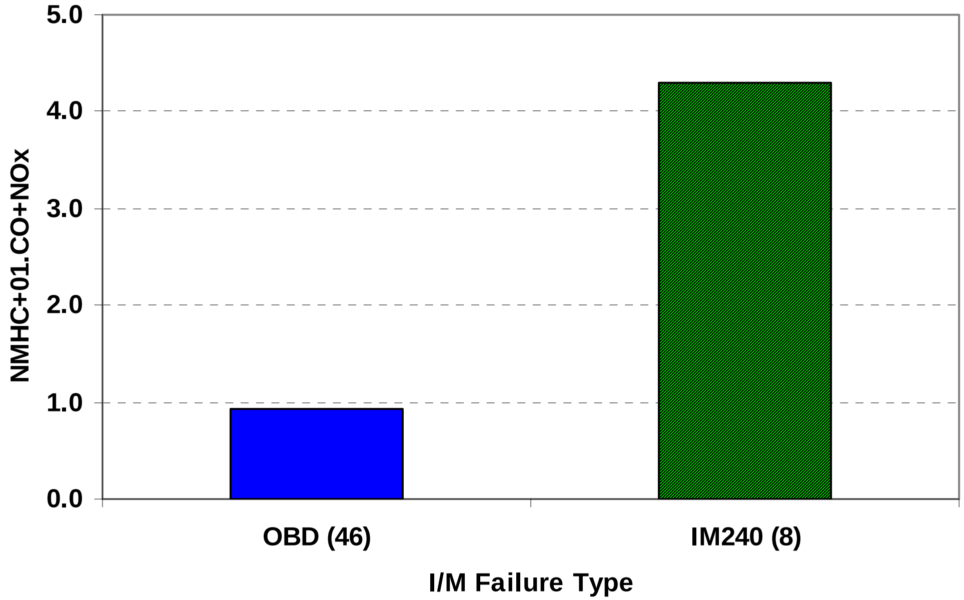
Dollars/Gram Reduction

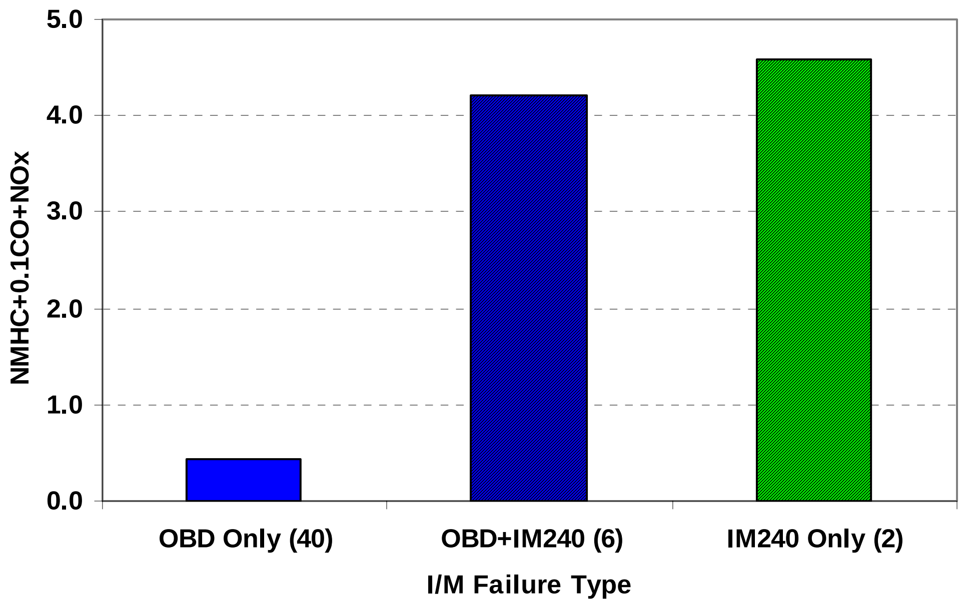
(NMHC+0.1CO+NOx)





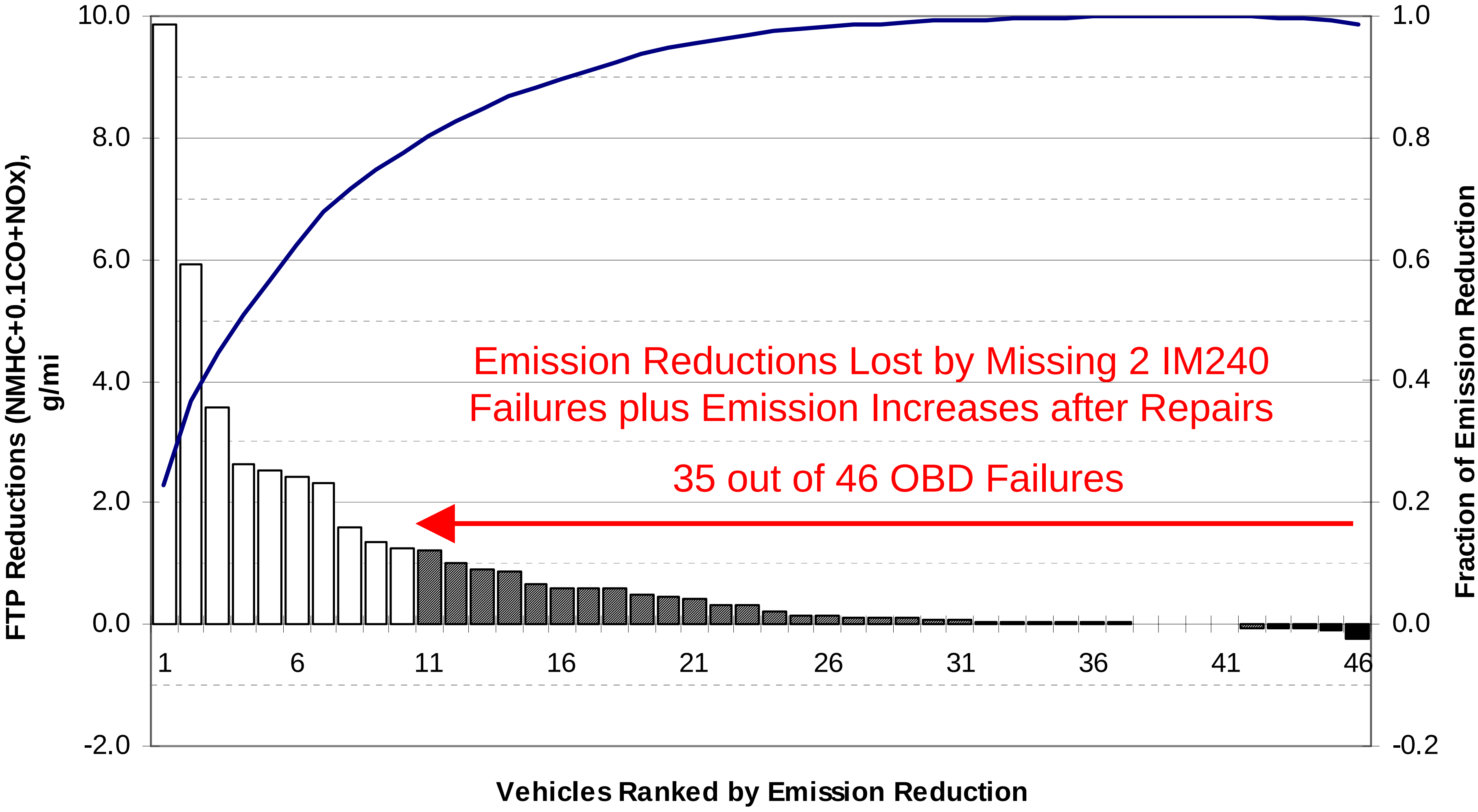
Grams Reduction/Repair





Summary Data

I/M Failure	N	Total Repair Costs	Cumulative Reduction, gr/mi	Costs per Repair	Repair Effectiveness, $/gram
MIL/OBD	46	$20,867	42.6	$454	$489/gram
MIL + IM240	6	$1,799	25.3	$300	$71/gram
IM240 but no MIL	2	$736	9.2	$368	$80/gram
MIL but no IM240	40	$19,068	17.4	$476	$1,098/gram



10.0
8.0
6.0
4.0
2.0
0.0
-2.0
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
1
6
11
16
21
26
31
36
41
46
FTP Reductions (NMHC+0.1CO+NOx), g/mi
Fraction of Emission Reduction
Vehicles Ranked by Emission Reduction
Emission Reductions Lost by Missing 2 IM240 Failures plus Emission Increases after Repairs
35 out of 46 OBD Failures

Findings

Under ideal conditions, where the motorist was removed from interaction with the technician and the technician knew his/her work was being monitored:

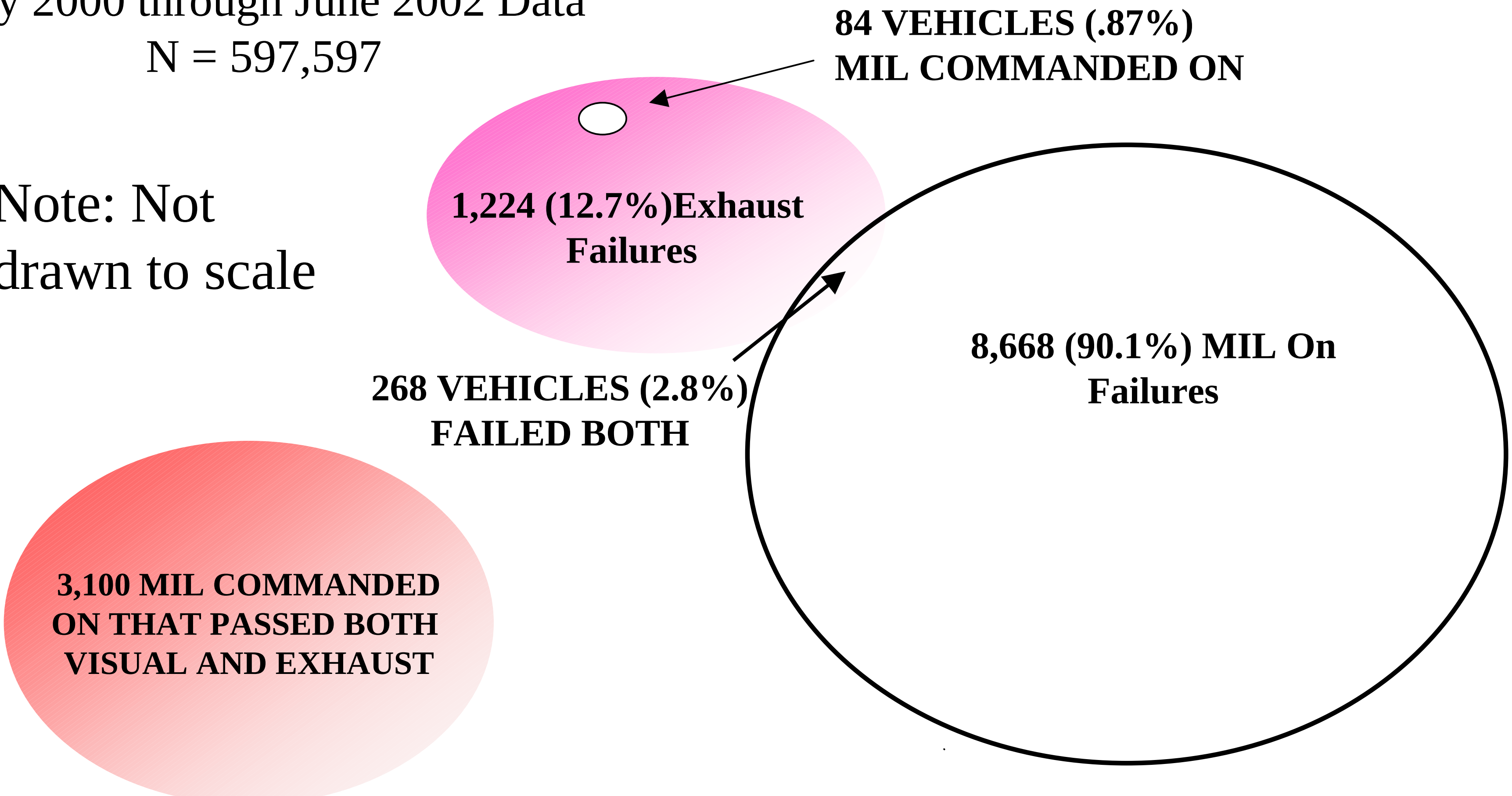
- Repairs from 8 vehicles failing the IM240 captured 81% of the OBD reductions from 46 vehicles
- The most expensive repairs were OBD repairs
- The largest emission reductions came from vehicles that failed the IM240
- Half of the study's net emission reductions came from only 4 of the 46 vehicles
- OBD false passes plus net emission increases meant that 35 of the 46 OBD-repaired vehicles produced no net improvement to air quality (roughly ¾ of the study's total repair costs)

“Lack of Overlap” Problem

EVALUATION OF COLORADO'S I/M DATA
OBD vs IM240
1996 and Newer Vehicles

July 2000 through June 2002 Data
N = 597,597

Note: Not drawn to scale



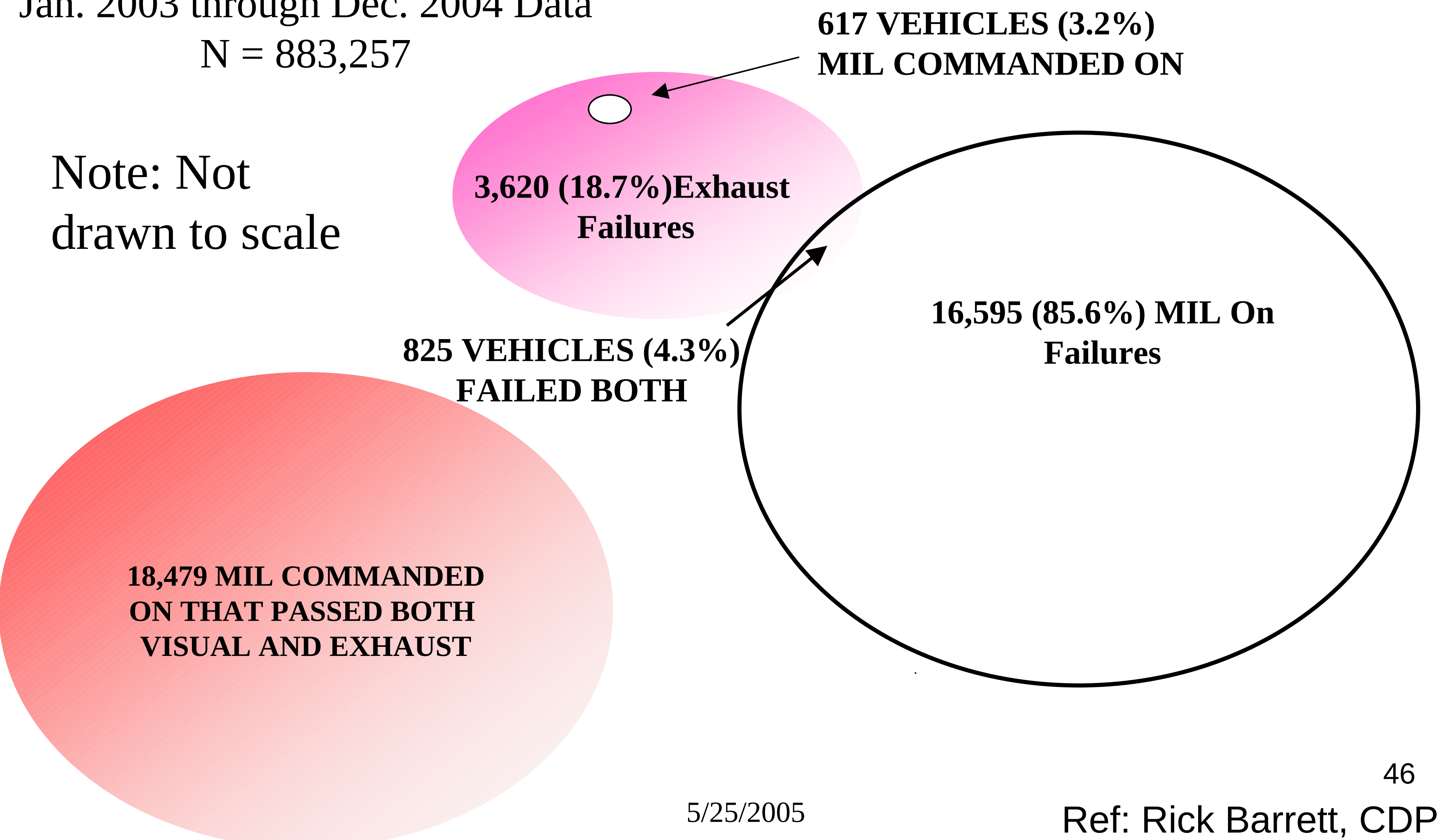
Ref: Rick Barrett, CDPHE

EVALUATION OF COLORADO’S I/M DATA
OBD vs IM240

1996 and Newer Vehicles

Jan. 2003 through Dec. 2004 Data
N = 883,257

Note: Not drawn to scale



Ref: Rick Barrett, CDPHE

“Lack of Overlap” Problem

- OBD serves as an early-warning system to the motorist that something might be wrong; however, it is far too stringent.
- OBD/MIL testing in an I/M program fails many more vehicles than does tailpipe testing, because the OBD standards are far more stringent than exhaust cutpoints.
- In an I/M setting, an OBD-only inspection-and-repair program will worsen air quality over the near term rather than improve it, given that the highest emitters are missed by OBD, while OBD identifies many marginal and low emitters with little emissions benefit at large costs to society.